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HALL-TYPE BUILDINGS

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Abstract

The first part of the article defines some fundamental concepts, and it is a brief historical survey of some significant, existing hall-type buildings and of the development trends of external wall and roof structures. It outlines the relevant domestic conditions and construction tasks.

The second part provides detailed information on the space demand of halls with swimming pools and sports halls of different size, and on the expected span of the main structure in case of halls with grandstands.

The third part discusses the selection of large-span structures, considering functional and architectural aspects, and the relation of internal space and the volume of the building. The following types of structure are covered: steel structures, timber structures, combined steel and timber structures, reinforced concrete structures, pneumatic, suspended and prestressed tents.

In the fourth part, various sets of roofing layers, in relation to materials and the shape of the large-span structure, are illustrated with examples.

Systems of wall structure, selected for the main structure, are covered in the fifth section.

The demand for natural lighting and the means of providing natural lighting in halls, assuming walls and roofs of various construction materials and structural systems, are introduced in the sixth section. Opening roofs above large-span structures of multi-purpose halls are illustrated with examples.

The seventh part discusses problems of rainwater drainage in halls, while the eighth part analyses aspects of building physics, acoustics and fire protection.

The ninth part is a comprehensive summary.

Keywords: large-span structures, external wall and roof structures.

The architectural, static and building engineering design requires close cooperation and harmonisation of special fields in case of all building types, however, the importance and the scope of these fields may vary widely.

One- and two-storeyed, residential and lodging buildings are generally characterised by simple structural systems and diverse architectural design.

Designing the load-bearing structures of multi-storey, cellular lodging and office buildings is, in most cases, an engineering task of average difficulty.

Similarly, the design process of prefabricated industrial structures, applying industrialised technology at manufacture, can be well-rationalised even in case of complex functions.

In case of the above-mentioned types of buildings, dealing with problems of building construction requires only basic knowledge of the subject, and an effective solution can be easily found.

However, some industrial buildings and, more generally, hall-type buildings of complex volume feature such architectural, building constructional and static problems, which must be analysed applying the classical structural principles in an innovative way.

The question arises, what does a hall and a hall-type building mean? These may be defined as a building or a part of a building that has a clear span over 18–20 m.

Building parts of small and medium-sized spaces often form complex building volumes due to the connection of various functions. (E.g. educational facilities with a sports hall, training pool or gallery, including a small stand or not.) In case of large spans, the hall and service spaces, or those of other use, are usually integrated within one building volume (e.g. in the Skydome in Toronto).

Nevertheless, it is the hall in a building that primarily determines its function and volume, which is basically influenced by the structural system of the large-span space.

Selecting a structural system for hall-type buildings is a very complex task, since the architectural concept must be harmonised with static, building constructional and building engineering aspects in such a way that the “final product”, i.e. the spatial and volume proportions, the facades and materials of the building, should be aesthetic and harmonious, it should fit in its environment, and the plan should be economically realisable.

The architectural concept and functional arrangement of a building is fundamentally based on its purpose. The great majority of hall-type buildings are sports halls, leisure or multi-purpose facilities. The main parameters of the hall need to be established as early as the initial stage of design, at the development of the main concept, at which the following points should be considered:

- sports technology regulations: dimensions of the arena or swimming pool hall, minimum clear height etc.,
- dimensioning rules and other regulations concerning galleries or grandstands, providing sufficient space according to seating capacity,
- space demand of the radio, the television and the press.

In case of other hall-type buildings, dimensioning and space demand of the hall are based on the functional and technological requirements of the facility (which is the seating capacity in case of lecture halls and theatre auditoriums, and the size of displayed objects in case of exhibition halls).

Supports of the large-span structure should not be placed in the audience area, yet the span should be designed to be the minimum possible, as internal forces and costs generally grow exponentially if the span increases.

At the selection of a structural system, the following conditions need to be considered, besides the required span: the internal space and external volume of the projected building, the site and its topographical forms, building density, number of floors, building height and typical roof shapes of the surrounding buildings, and the magnitude of the settlement.

According to the design programme, decisions can be made about the proportion of the floor area of the hall and the service units, the ground-floor shape and geometry of the building, and the options of connecting building volumes. A demand for natural lighting may occur, which can be satisfied by skylights, and an opening roof may also be a requirement. Both of them may change the concept of the main structural system.

It is essential that static, building constructional, production technological, constructional and organisational problems be analysed at the selection of a large-span structure. For instance, soil mechanical properties of the site, such as ground strata, the level and load-bearing capacity of firm soil, the level and chemical composition of ground water, may be determining factors.

The external wall and roof are closely connected with the large-span structure, and its layer system is largely dependent on the properties of air condition in the hall, i.e. temperature and humidity.

The most important aspects in the organisation of the construction process are as follows: the proportion of structural elements that can be prefabricated in a factory, portability of elements, options of on-site assembly, need for partial or entire scaffolding, specific material demand and labour demand at on-site assembly.

A subject in this topic is going to introduce students to the application fields of various structural systems, considering a variety of materials and static models, in case of certain types of buildings. Steel frames, trusses, plated steel beams, arches, suspended structures and spatial trusses will be introduced and illustrated with examples from Hungary and abroad.

For large-span structures, glued-laminated timber structures may also be selected because of their favourable characteristics, such as aesthetic appearance, favourable building physical parameters, resistance to chemical effects, economy, low density and relatively high ultimate strength ($R_u = 10 - 23$ N/mm^2).

The application field, span range and typical structural dimensions of simply supported beams, three-hinged frames, three-hinged arched frames, three-hinged arches and trusses are introduced through concrete examples and illustrated with a set of figures. This overview covers not only orthogonal but also central and elliptical spaces.

Combined glued-laminated timber and steel structures represent a new chapter in timber construction. The reason for this path of development is that cross-sectional dimensions of timber elements can be reduced and that timber can be replaced with various steel elements (flat bars, pipes or wires) in the tensile chord, thus making the structure lighter and the internal space more transparent.

Large-span reinforced concrete structures were originally represented by cast-in-place shells of different kinds, which were later gradually replaced by prefabricated structures. However, large-span reinforced concrete structures faded into the background, especially in the range of very large spans, due to their unfavourable characteristics, e.g. high density, limited portability and lifting weight, even if this material has a number of favourable attributes, such as high strength, durability and fire resistance.

In hall-type public buildings, prefabricated, prestressed beam and roof elements are applied up to 25 m span, while primarily folded plates of various cross-sections, and hyperbolic paraboloid and barrel-vaulted shells are designed for 25 to 40 m spans.

Central buildings of up to 40 m diameter can be spanned by Binishell-type dome shells, and the cover structure of larger spans can be thin-walled, ribbed shells and folded plate elements with cast-in-place supplements. In the textbook and in classes, the aspects that represent guidance and limits at the selection of structures will be picturesquely introduced, assessed and illustrated with examples.

Pneumatic and prestressed tents may be employed as economical roofing of hall-type public buildings only in case of spaces of low demand of thermal conditions.

The subject will introduce the materials, technical parameters and lifespan of tents, and, in the range of pneumatic structures, pneumatic tents, cushions and tubes. All prestressed tents are double-curvature hyperbolic surfaces, and they are supported by steel pipes, glued-laminated timber arches, cables hanging from arches or masts.

The main shape and volume of the selected large-span structure, regardless of its material, may be determining at the design of roofing layers.

Roofing layers of buildings of simple volume, with flat roof, are that of conventional single-shell warm roofs in general, and this may be altered only if it is reasonable to do so. Slightly sloped and pitched roof structures are, regardless of internal air condition, generally double-shell cold roofs, for reasons concerning the roofing material and its structural details.

Well-known design principles of warm and cold roofs may be altered or improved in case of restricted ways of rainwater drainage and extremely large roof surfaces. A design task at warm roofs is selecting the material of the tapered subbase or another layer that ensures a slope for the roof, and design problems may occur due to its self-weight and major deformations of the main structure. In case of double-shell systems, design tasks include designing the thickness of the ventilated void and the area of air inlet and outlet openings, ensuring a sufficient distance between them, designing the backing of the roof covering that allows air flow and does not form heat bridges, and harmonising the roof with the building engineering system, taking openings and skylights into account.

The efficient ventilation requires a sufficient flow length, i.e. the distance between the air inlet and outlet, which should not be more than the so-called critical length, that is the sum of the length of ‘ventilated’ and ‘transient’ roof segments. In a roof segment beyond this length, there would be saturated vapour, which can condense on the internal surface of the external shell and damage the structure.

The curriculum includes a detailed introduction to sets of roofing layers for large-span structures of different materials and structural systems.

The chapter on steel structures covers structural details of a variety of steel and glass cover structures (e.g. the cover of the museum courtyard in Hamburg and the multi-purpose congress hall in Linz). See *Fig. 1* for the leisure spa with a glass dome in Nekarsulm, named ‘Aquatoll’.

The applied system of roofing layers of various suspended structures is single-

Fig. 1. Aquatoll in Nekarsulm

shell warm roof. Formerly, reinforced concrete roofs of heavy elements were constructed, which stabilise the cable system (e.g. the covered swimming pool in Wuppertal and the sports hall in Bremen), but they were replaced later by mounted structural solutions, which can better adjust to deformations (Stockholm, Bratislava, Olympiadach, Munich and Budapest).

The chapter entitled roofing layer systems of large-span timber and combined timber and steel structures introduces single and double-shell, panelled solutions. The swimming pool hall of the Solebad in Bad Dürrheim is covered by an arched grillage of glued-laminated timber with the following roofing layers: double plank covering, 3 layers of heat insulation and 1.2 mm thick vinyl sheeting fixed mechanically (*Fig. 2*).

The roofing layers over large span reinforced concrete structures are mostly single-shell systems, only thin-wall structures demand double-shell roofs.

A demand for natural lighting in hall has been characteristic of each era but it was usually limited by the actual technological level. In today's architectural practice, examples of efficient natural lighting occur in leisure facilities and adventure spas, and in case of grand stand covers and large spaces in traffic. In sports facilities, natural lighting without sun exposure and glare must be ensured by architectural means such as shaded external glass walls, skylights of north orientation and lighting openings that restrict sun exposure.

A nice arrangement of skylights, harmonised with a simple and rational system of rainwater drainage, and a set of air engineering conduits if necessary, can give an internal space under a large-span structure an aesthetic, harmonic appearance.

In case of a large majority of hall-type buildings, it is an essential condition

Fig. 2. Solebad in Bad Dürrheim

that they are of multi-purpose use, which especially applies for halls of increasing capacity. It has been observed that central halls, the dimensions of which kept increasing until the end of the 1980s, do not tend to exceed a span of 200 to 220 m. The objective is not increasing the size and capacity of buildings, instead, there is a trend towards flexible systems of cover structures over halls which feature diverse options for openings and multi-purpose use assuming any kind of weather conditions.

The roof structure of the Sky-Dome in Toronto, built in 1989, comprises a fixed and a mobile dome segment and two mobile barrel vault sections. The roof can completely be opened up within 20 minutes, converting 91% of the seats into an open-air grand stand (*Fig. 3*).

The cover structure over the tennis hall named Ariake Colosseum, which has a seating capacity of 10 thousand, was erected in 1991. The structure can be opened up by sliding the northern roof unit to a certain extent and the southern roof unit to a larger extent on roller supports.

The roof structure of Fukuoka Dome, completed in 1993, consists of three identical roof sections; one is fixed and two of them are mobile. By moving the mobile sections over the fixed one, two third of the hall opens up.

The roof structure of Universal Dome comprises two mobile dome segments and a barrel vault section. There are several variations in the way they can be opened up, according to weather conditions and wind direction, and a need of sunshine or shade.

Dual Dome is a double roof structure consisting of two sets of semidomes.

Fig. 3. Sky-Dome in Toronto

One of the roof units has completely closed roof covering, equipped with building physical, acoustical, and air conditioning appliances providing optimal conditions, while the other unit has translucent roof covering with a rainwater drainage system. Opening alternatives, which ensure the multi-purpose use of the hall, adjustable to weather conditions.

Further chapters of the curriculum cover problems of rainwater drainage, building physics, acoustics and fire protection, and make suggestions about how to select external wall and roof structures of certain types of hall-type buildings.

The textbook is regarded as a publication that bridges a gap, as it provides a wide scope of knowledge of the design process, which harmonises architectural, building constructional and static design, thus it can be well used in the education of students of civil engineering.